

TOPIC E – ENVIRONMENTAL CHEMSITRY E1-9 SL : E1-12 HL

IB Chemistry
Topic E - Enviro



E: Environmental Chemistry

- *Human activities involve intensive use of limited resources found in air, water and soil. Many of these activities produce waste products that build up in the environment to produce pollution with increasingly local and global effects. An understanding of this impact is essential within and beyond the study of chemistry. This option has many opportunities for discussing aim 8 issues and the international dimension.*



E1 Air pollution - 2 hours

- E.1.1 Describe the main sources of carbon monoxide (CO), oxides of nitrogen (NO_x), oxides of sulfur (SO_x), particulates and volatile organic compounds (VOCs) in the atmosphere. (2)
- E.1.2 Evaluate current methods for the reduction of air pollution. (3)



E2 Acid deposition - 1.5 hours

- E.2.1 State what is meant by the term acid deposition and outline its origins. (1)
- E.2.2 Discuss the environmental effects of acid deposition and possible methods to counteract them. (3)



E1 **E3 Greenhouse effect - 1.5 hours**

- E.3.1 Describe the greenhouse effect. (2)
- E.3.2 List the main greenhouse gases and their sources, and discuss their relative effects. (3)
- E.3.3 Discuss the influence of increasing amounts of greenhouse gases on the atmosphere. (3)



E4 Ozone depletion - 1.5 hours

- E.4.1 Describe the formation and depletion of ozone in the stratosphere by natural processes. (2)
- E.4.2 List the ozone-depleting pollutants and their sources. (1)
- E.4.3 Discuss the alternatives to CFCs in terms of their properties. (3)



E1 E5 Dissolved oxygen in water - 1.5 hours

- E.5.1 Outline biochemical oxygen demand (BOD) as a measure of oxygen demanding wastes in water. (2)
- E.5.2 Distinguish between aerobic and anaerobic decomposition of organic material in water. (2)
- E.5.3 Describe the process of eutrophication and its effects. (2)
- E.5.4 Describe the source and effects of thermal pollution in water. (2)



E6 Water treatment -2.5 hours

- E.6.1 List the primary pollutants found in waste water and identify their sources. (2)
- E.6.2 Outline the primary, secondary and tertiary stages of waste water treatment, and state the substance that is removed during each stage. (2)
- E.6.3 Evaluate the process to obtain fresh water from sea water using multistage distillation and reverse osmosis. (3)



E7 Soil - 2.5 hours

- E.7.1 Discuss salinization, nutrient depletion and soil pollution as causes of soil degradation. (3)
- E.7.2 Describe the relevance of the soil organic matter (SOM) in preventing soil degradation, and outline its physical and biological functions. (2)
- E.7.3 List common organic soil pollutants and their sources. (1)



E8 Waste - 2 hours

- E.8.1 Outline and compare the various methods for waste disposal. (3)
- E.8.2 Describe the recycling of metal, glass, plastic and paper products, and outline its benefits. (2)
- E.8.3 Describe the characteristics and sources of different types of radioactive waste. (2)
- E.8.4 Compare the storage and disposal methods for different types of radioactive waste. (3)



E9 Ozone depletion - 1 hour

- E.9.1 Explain the dependence of O₂ and O₃ dissociation on the wavelength of light. (3)
- E.9.2 Describe the mechanism in the catalysis of O₃ depletion by CFCs and NO_x. (2)
- E.9.3 Outline the reasons for greater ozone depletion in polar regions. (2)



HL Material

Topics 10-12 are for HL students only



E10 Smog - 2 hours

- E.10.1 State the source of primary pollutants and the conditions necessary for the formation of photochemical smog. (1)
- E.10.2 Outline the formation of secondary pollutants in photochemical smog. (2)



E11 Acid deposition - 1 hour

- E.11.1 Describe the mechanism of acid deposition caused by the oxides of nitrogen and oxides of sulfur. (2)
- E.11.2 Explain the role of ammonia in acid deposition. (3)



E12 Water and soil - 3 hours

- E.12.1 Solve problems relating to the removal of heavy-metal ions, phosphates and nitrates from water
 - by chemical precipitation. (3)
- E.12.2 State what is meant by the term cation-exchange capacity (CEC) and outline its importance. (2)
- E.12.3 Discuss the effects of soil pH on cation-exchange capacity and availability of nutrients. (3)



Part 1: Air Pollution



E1 Air pollution - 2 hours

- E.1.1 **Describe** the main sources of carbon monoxide (CO), oxides of nitrogen (NO_x), oxides of sulfur (SO_x), particulates and volatile organic compounds (VOCs) in the atmosphere. (2) *Include both natural and anthropogenic sources. Equations should be used as appropriate.*
- E.1.2 **Evaluate** current methods for the reduction of air pollution. (3) *Examples include: CO - catalytic converters, NO_x - control of fuel/air ratio, SO_x—alkaline scrubbing, limestone-based fluidized beds, particulates - electrostatic precipitation, VOC's - catalytic converters*



E1.1 – Sources of Gases

- E.1.1 **Describe** the main sources of carbon monoxide (CO), oxides of nitrogen (NO_x), oxides of sulfur (SO_x), particulates and volatile organic compounds (VOCs) in the atmosphere. (2) *Include both natural and anthropogenic sources. Equations should be used as appropriate.*



E1.1 - Pollution

- **Pollution** refers to changes in the equilibrium (or balance) of biological and non-biological systems, as a result of human activity
- Although many so-called pollutants are substances that occur naturally, such as ozone or carbon dioxide, human activity has led to an increase in the concentrations of such substances, which upsets the delicate balance of natural cycles
- The **atmosphere** consists of a relatively thin layer of gas surrounding the Earth. (to 100km)



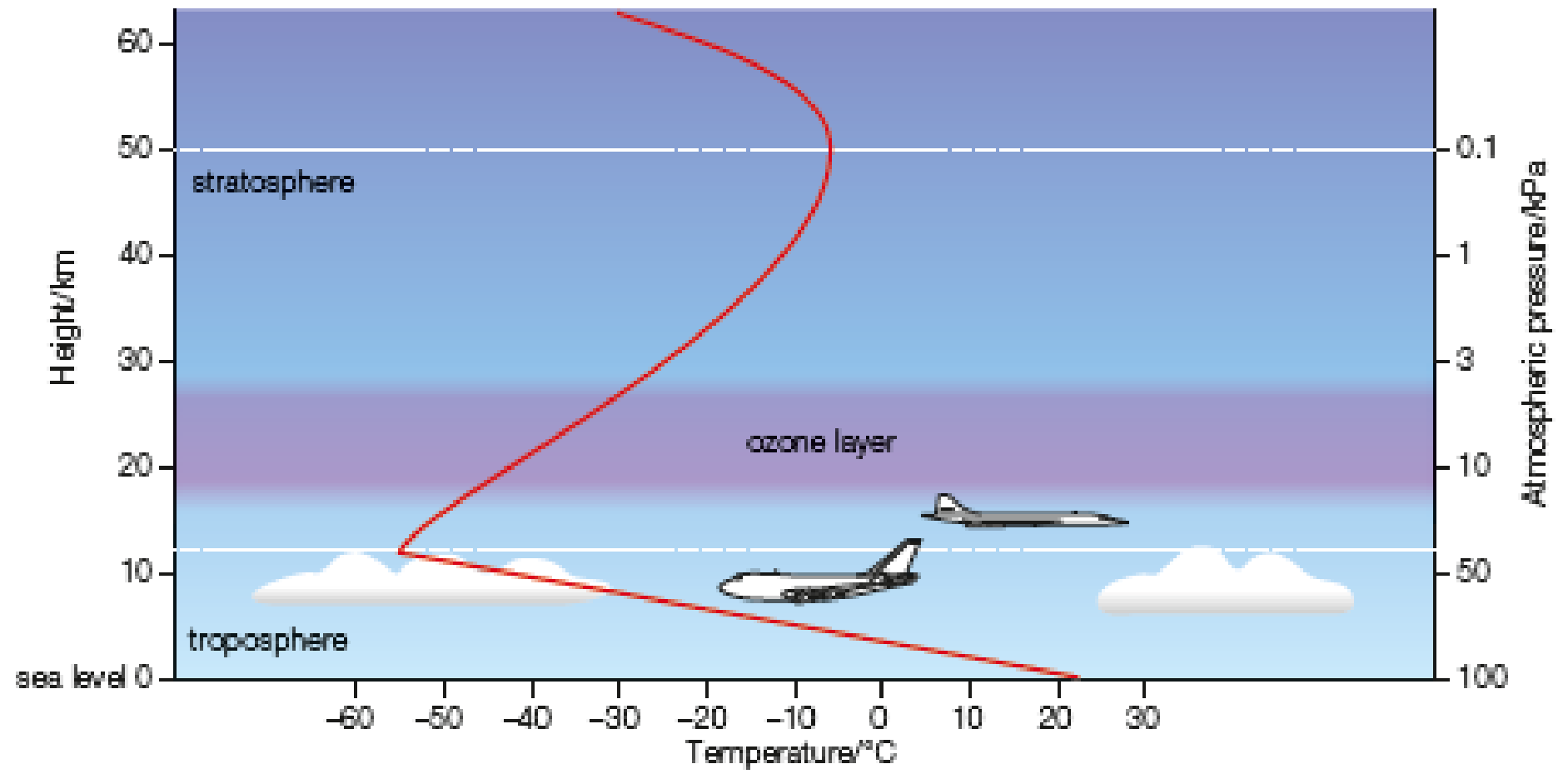
By comparison, the earth is 6400km in radius

E1.1 – Layers of the Atmosphere

- The atmosphere consists of four layers, separated by a change in temperature gradient
 - Troposphere
 - ◆ Most of human activity takes place here
 - ◆ Up to 10-12 km
 - ◆ 90% of matter in the atmosphere
 - Stratosphere
 - Mesosphere
 - Thermosphere



E1.1 – Atmospheric Layers



E1.1 - Troposphere

- In the troposphere temperature falls with increasing height, so that at a height of 12 km the temperature is about -55°C
- This temperature gradient allows convection currents (warm gases rise, cool gases sink) causing mixing in the atmosphere pollutants.
- Pollutants at ground level quickly spread throughout the troposphere (not true in stratosphere).
- Also, horizontal movement of air masses (wind) causes lateral dispersion of pollutants as well.



E1.1 – Composition of Atmosphere

Gas	Percentage composition (by volume)/%
Nitrogen	78.09
Oxygen	20.94
Noble gases (mostly argon)	0.93
Carbon dioxide	0.035
Water vapour	0–4
Other gases	Variable

Table 25.1 Composition of the troposphere



E1.1 – Atmospheric Pollutants

- As discussed, many gases we consider pollutants, also occur naturally (CO, CO₂, etc)
- **Anthropogenic**, or man-made, output is often not even a large proportion of the worldwide total but can cause issues due to high concentrations in localized areas.
- Many atmospheric pollutants arise from the combustion of fossil fuels in motor vehicles or in power stations. This effect has the potential to be minimized



E1.1 - Vocab

- The site from which pollutants originate is called the **source**.
- Sources may be direct or indirect from chemical reactions involving the emitted chemicals (such as CFC's)
- A **sink** is a process which removes the pollutant from the atmosphere. Sinks are often chemical reactions



E1.1 – Sources of Pollutants

Compound	Natural sources	Man-made sources
CO	Oxidation of methane (via a mechanism involving hydroxyl radicals), e.g. $\text{CH}_4 + \text{O}_2 \rightarrow \text{CO} + \text{H}_2 + \text{H}_2\text{O}$, volcanoes, forest fires, decomposition of chlorophyll	Incomplete combustion of fossil fuels, e.g. (petrol) $\text{C}_8\text{H}_{18} + 8.5 \text{O}_2 \rightarrow 8\text{CO} + 9\text{H}_2\text{O}$
CH_4	Intestinal fermentation in wild animals, termites, emissions from natural wetlands (Figure 25.2), etc.	Cattle rearing, emissions from rice paddies, leakages from land fills, sewage
Volatile organic compounds (VOCs)	Tree emissions – isoprene (C_5H_8) and monoterpenes (various isomers of $\text{C}_{10}\text{H}_{16}$)	Motor vehicles – evaporation and incomplete combustion, gas leakage, refinery emissions
Particulates	Wind-borne dust, sea spray and volcanoes	Incomplete combustion of fuels
NO	Forest fires, anaerobic processes in soils, electric storms	Combustion of oil, gas, coal, e.g. $\text{N}_2 + \text{O}_2 \rightarrow 2\text{NO}$
NO_2	Forest fires, electric storms	Combustion of oil, gas, coal, e.g. $2\text{NO} + \text{O}_2 \rightarrow 2\text{NO}_2$
N_2O	Emissions from denitrifying bacteria	Combustion of oil and coal
SO_2	Oxidation of hydrogen sulfide, volcanic activity, decay of biological material	Combustion of coal and heavy fuel oil (containing sulfur impurities), roasting or smelting sulfide ores, e.g. $\text{S} + \text{O}_2 \rightarrow \text{SO}_2$
H_2S	Anaerobic fermentation (eutrophication), volcanoes	Oil refining, animal manure, coke oven gas
H CXs (halogenoalkanes)		Solvents, aerosols, etc.
Ozone, O_3	From stratosphere, NO– NO_2 conversion	NO– NO_2 conversion
SF_6		Electrical insulators

Table 25.2 Summary of sources

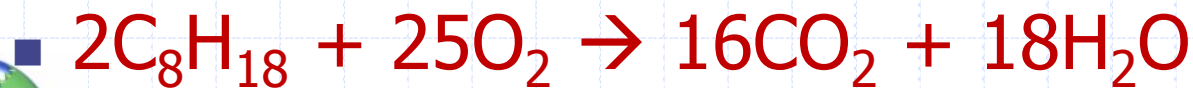
E1.2 – Reduction of Air Pollution

- E.1.2 **Evaluate** current methods for the reduction of air pollution. (3) *Examples include: CO - catalytic converters, NO_x - control of fuel/air ratio, SO_x—alkaline scrubbing, limestone-based fluidized beds, particulates - electrostatic precipitation, VOC's - catalytic converters*



E1.2 – Reduction of Pollution

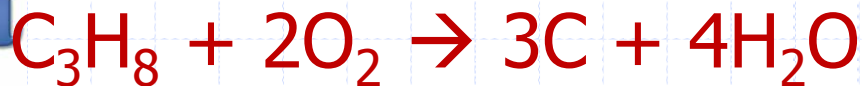
- In the internal combustion engine, hydrocarbon fuels are mixed with air, injected into a cylinder and ignited with a spark
- The resultant explosion forces the piston to move and is converted to the rotation of the crankshaft, which in turn drives the wheels of the vehicle
- We can have complete, partial, and incomplete combustion of the hydrocarbon, ideally it would be complete as follows:



Ratio of air/fuel (mass) is approx 15:1

E1.2 – Incomplete Combustion

- When the ratio of air/fuel (mass) is less than 15:1, the mixture is said to be '**rich**' and incomplete combustion ensues
- This results in the formation of carbon monoxide
 - $C_8H_{18} + 10O_2 \rightarrow 3CO_2 + 5CO + 9H_2O$
 - These unburnt hydrocarbon molecules (CO) are called **volatile organic compounds** (VOC's) from exhaust
- A very poorly designed (or maintained) engine may emit solid particles (soot) from the exhaust (rich)



E1.2 – Reaction with Nitrogen

- When the air/fuel ratio is increased the mixture is said to be '**lean**'. A lean mixture will not produce carbon monoxide
- When a mixture becomes 'lean' (excess O_2) the likelihood that oxygen will react with nitrogen in the air (78%) increases.
- Under extreme conditions (like in an engine) the two elements can combine to form nitrogen oxides NO_x which leads to 'misfire' in the engine (known as knocking) because the fuel ignites before the spark



E1.2 – Rich vs Lean

- An engine that runs 'rich' will produce a lot of power, but with poor fuel consumption and high emissions of CO and VOC's
- An engine that runs 'lean' will produce less power, less CO and VOC's, consume less fuel, but may produce more nitrogen oxides. When mixture is too lean, misfiring causes rise in VOC production
 - $\text{N}_2 + \text{O}_2 \rightarrow 2\text{NO}\bullet$ (remember the radical?)
 - $2\text{NO}\bullet + \text{O}_2 \rightarrow 2\text{NO}_2$
 - Localized in urban areas, causing health effects and contribute to the formation of acid rain



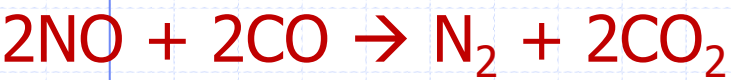
E1.2 – Catalytic Converter

- Three way **catalytic converter** is placed in exhaust systems of cars to treat the exhaust gases
- Consists of a fine mesh or honeycomb of ceramic material or metal, coated with a thin layer of finely divided platinum, rhodium, or palladium (these T-metals act as homogeneous catalysts, 13.5, 6)
- Three way refers to:
 1. Reduction of nitrogen monoxide to nitrogen
 2. Oxidation of unburnt hydrocarbons to carbon dioxide and water vapor
 3. Oxidation of carbon monoxide to carbon dioxide



E1.2 – Catalytic Converter

- First, gases pass over metal catalyst, reacting NO and CO



- Then, pass over oxidation catalyst (rhodium). If a proper ratio of air/fuel exists, there is proper O₂ remaining for this:

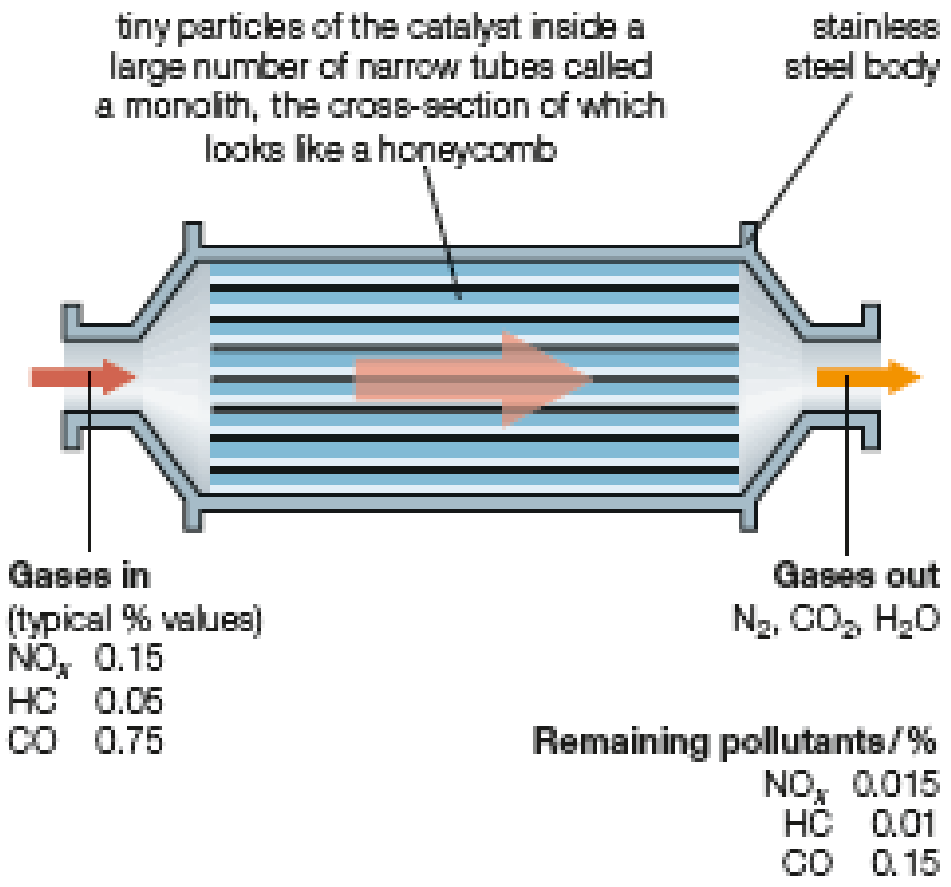
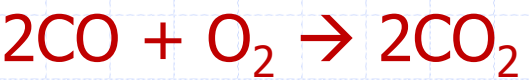


Figure 25.4 A three-way catalytic converter



E1.2 – Sulfur as Pollutant

- SO₂ (sulfur dioxide) is an important primary pollutant.
 - It's a pungent smelling toxic gas
 - damages the respiratory system and may lead to asthma attacks.
 - Highly soluble in water
 - Contributes to formation of acid rain



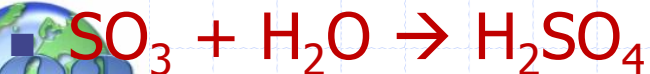
E1.2 – Primary/Secondary Pollutants

- **Primary pollutants** are emitted directly from the sources and remain unchanged once they enter the environment (particulate matter, inorganic gases, SO₂, etc)
- **Secondary pollutants** are formed in the atmosphere by chemical reactions involving primary pollutants and gases normally present in the air.
- Most man-made sulfur dioxide emissions arise from the sulfur that exists as an impurity in coal which is burned extensively in many power plants



E1.2 – Sulfur reactions

- Sulfur is oxidized during the combustion process
 - $S + O_2 \rightarrow SO_2$
- Sulfur dioxide dissolves and reacts with water to produce sulfurous acid, H_2SO_3
 - $SO_2 + H_2O \rightarrow H_2SO_3$
- Sulfur dioxide also undergoes photochemical oxidation in the atmosphere. This occurs in water droplets in which SO_2 is dissolved, and is catalyzed by particulates (soot, etc)
 - $2SO_2 + O_2 \rightarrow 2SO_3$
- Sulfur trioxide dissolves and reacts with water to produce sulfuric acid



E1.2 – Reducing SO₂ Emissions

- There are three methods by which sulfur dioxide emissions from power stations can be limited
 - The coal or oil can be refined to remove sulfur before combustion
 - **Fluidized bed combustion** (FBC) reduces the amount of sulfur oxides resulting from combustion
 - **Flue gas desulfurization** (FGD) removes sulfur dioxide from the exhaust gases before they leave the power station flue (chimney)



E1.2 – Fluidized Bed Combustion

- This process suspends the solid coal on an upward flowing jet of air during combustion
- Coal dust is mixed with limestone powder (CaCO_3) and blasted into the furnace with a jet of air. The jet of air suspends the solid particle so they flow like a fluid
 - $\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$
 - $2\text{CaO} + 2\text{SO}_2 + \text{O}_2 \rightarrow 2\text{CaSO}_4$
- The Calcium sulfate can then be removed by **electrostatic precipitation**



E1.2 – Flue Gas Desulfurization

- Sulfur dioxide emissions can be removed from the flue gases by passing the gases through a **suspension** of calcium carbonate and calcium oxide in water. Product is calcium sulfite
 - $\text{CaCO}_3 + \text{SO}_2 \rightarrow \text{CaSO}_3 + \text{CO}_2$
 - $\text{CaO} + \text{SO}_2 \rightarrow \text{CaSO}_3$
- Calcium sulfite is then further oxidized, producing calcium sulfate
 - $2\text{CaSO}_3 + \text{O}_2 \rightarrow 2\text{CaSO}_4$



E1.2 – Particulate Emissions

- **Particulate** emission refers to the generation of small particles of solid or liquid. Some such pollutants are visible to the naked eye, but most are too small to be seen.
 - Metal particles
 - Metal oxide particles
 - Fly ash
 - Asbestos dust
 - Organic particles
 - Aerosol mist



E1.2 – Metal Particulates

- During metal fabrication and manufacturing, small particles of metals are released into the atmosphere.
- Also released by mechanical action such as vehicle brake pads (Cu and Zn)



E1.2 – Metal Oxide Particles

- When coal containing residual metal compounds (such as sulfides) is burned, the metals are oxidized, forming particles of metal oxides such as iron (III) oxide, Fe_2O_3 .



E1.2 – Fly Ash

- Fly ash is a combination of very fine carbon, hydrocarbon and metal oxide particles released during the combustion of fossil fuels
- Most fly ash is filtered out in flues, but some very fine particles escape into the atmosphere



E1.2 – Asbestos Dust

- Asbestos is a silicate material with insulating and heat-resistant properties
 - Hence, it is used as fire-retarded and insulation in building materials, car brake lining, etc
- Released into the atmosphere during mining and manufacturing processes.
- Not used often any more since the fine particles are known to cause serious cancers of the chest and respiratory system



E1.2 – Organic Particles

- Carcinogenic hydrocarbons can be generated by incomplete burning, including biomass burning.
 - Benzopyrenes, chrysene, benzanthracene
- These substances are readily absorbed onto the surface of soot particles, rendering the soot particles much more harmful



E1.2 – Aerosol Mist

- When nitrogen oxides or sulfur trioxide combine with moisture, a fine mist of acidic particles is formed.
- For nitrates, ammonia or metal must be present.
- Sulfuric acid can form in power station chimneys, but is usually rapidly neutralized by ammonia once it has been emitted and mixed in the atmosphere.



E1.2 – Removal of Particulates

- Via **sedimentation** which relies on letting heavy particles settle out under gravity, or by filtration, in which simple fabric filters capture particles.
- Most effective method is **electrostatic precipitation** – which has two sections
 - Ionization section, consists of a mesh with thin wires, carrying an electrical charge. Flue gas passes through this mesh, causing any solid or liquid particles to acquire charge
 - Collection section, consists of metal plates carrying the opposite charge. Particulates are attracted to the plates, and stick. Plates are shaken at intervals to dislodge the build-up layer of particles, then they are removed.



E1.2 – Human Health Impacts

- Body's defense system to particulates is the **hair-like cilia** on surface of the respiratory tract. Captures large particles and moves them to the mouth where they are swallowed
- Particles still cause harm as some can be introduced to the blood stream.
- Heavy metals and their oxides enter the body this way.
- The smallest particles are the most harmful because they are able to reach the deepest parts of the lungs as the cilia miss them.
- In the lungs they can contribute to asthma and bronchitis



E1.2 – Secondary Effects

- Atmospheric particles offer a catalytic surface on which other atmospheric pollutants can be absorbed, leading to increased rates of potentially harmful reactions.
 - For example, sulfur dioxide may be converted to sulfur trioxide on the surface of soot or fine metallic particles.

